DOCUMENT RESUME

ED 309 758 IR 013 919

AUTHOR Orlansky, Jesse
TITLE The Cost-Effectiveness of Military Training.
REPORT NO DS/A/DR(85)167
PUB DATE Jan 85
NOTE 48p.; Paper presented at the Symposium on Military Value and Cost-Effectiveness of Training (Brussels, Belgium, January 1985).
PUB TYPE Information Analyses (070) -- Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; *Computer Managed Instruction; *Computer Simulation; *Cost Effectiveness; Evaluation Methods; Information Technology; Input Output Analysis; Instructional Effectiveness; Intermode Differences; Military Training; Postsecondary Education

ABSTRACT

Flight simulators, computer-based instruction (including both computer-assisted and computer-managed instruction), and maintenance training simulators are as effective, when used for training, as aircraft, conventional classroom instruction, and actual equipment, respectively. Data from about 100 studies are reported to support this finding. These methods of instruction save student time, investment, and operating costs except that credible cost data are not available for computer-based instruction. These findings apply primarily to training at schools. Much less is known about the transfer of training from school to job, except for the effective transfer of skills from flight simulators to aircraft. Little has been done to determine trade-offs between optimum combinations of effectiveness and cost. (25 figures and 20 references) (Author/GL)

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ED309758

In: Proceedings of the Symposium on the Military Value and Cost-Effectiveness of Training (DS/A/DR(85)167). Brussels, Belgium: NATO Headquarters, Defence Research Group on the Defence Applications of Operational Research, January 1985.

THE COST-EFFECTIVENESS OF MILITARY TRAINING

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ABSTRACT

Flight simulators, computer-based instruction and maintenance training simulators are as effective, when used for training, as aircraft, conventional, classroom instruction and actual equipment, respectively. Data from about 100 studies are reported to support this finding. These methods of training save student time, investment and operating costs except that credible cost data are not available for computer-based instruction. These findings apply primarily to training at schools. Much less is known about the transfer of training from school to job, except for the effective transfer of skills from flight simulators to aircraft. Little has been done to determine trade-offs between optimum combinations of effectiveness and cost.

THE COST-EFFECTIVENESS OF MILITARY TRAINING

1. INTRODUCTION

Training is what all military forces do to be ready for combat. It requires large installations, such as schools and ranges, and consumes substantial resources for the pay and allowances of students and instructors, fuel and ammunition. The only time that military forces do not train is when they are engaged in combat.

In the United States, initial individual training for recruits, officers, specialized technicians and pilots cost 17.9 billion dollars in Fiscal Year 1985 (Figure 1).[1] Specialized skill training accounts for the largest number of students and the largest total cost; the highest cost per student is for flight training. About 75 percent of this student load was due to the entry of new personnel into military service; this is a consequence of an all-volunteer force and relatively short military careers where about one-quarter of the entire military force leaves each year. When we combine the number of man-years of students and instructors, we see that 12 percent of all military man-years are always assigned to schools (Figure 2).

Individual training at school is merely the beginning rather than the end of military training. When training at school has been completed, personnel are assigned to an operating unit such as an air squadron, destroyer, tank or infantry unit where they receive crew, unit or team training (also called collective training) and participate in live firings and field exercises. The amounts and costs of these types of training are in addition to those noted above for individual training.

2. TRAINING AND EDUCATION

There are some differences between training conducted by military forces and industry and education conducted by schools and colleges, but these relate more to matters of policy and management than to subject matter, methods of instruction or nature of students. For convenience, we use the term "training" to refer to instruction intended to qualify a person to perform a specific job or task, such as repairing a truck, operating a computer or maintaining a radar set; "education" has a well-known, more general purpose where subjects like mathematics, language, and

TYPE OF TRAINING	NUMBER OF STUDENTS (INPUT, 000)	COST (BILLIONS)
RECRUIT	374	$ 1.3
ARMY ONE-STATION UNIT*	95	0.4
OFFICER ACQUISITION	16	0.5
SPECIALIZED SKILL	1396	4.4
FLIGHT	16	2.3
PROFESSIONAL DEVELOPMENT	53	0.7
MEDICAL		0.6
(SUPPORT COSTS)		7.6
TOTAL	1950	$17.9

*RECRUIT AND INITIAL SKILL TRAINING

5-11-84-3 SOURCE: MILITARY MANPOWER TRAINING REPORT FOR FY 1985

FIGURE 1. Individual training at military schools, FY 1985

	MAN-YEARS (000)	
	MILITARY	CIVILIAN
STUDENTS	261	—
INSTRUCTORS/SUPPORT	132	61
TOTAL	393	61
DoD END-STRENGTH	3270	999
PERCENT IN TRAINING	12%	6%

NOTE: INCLUDES ACTIVE MILITARY AND RESERVE CONPONENTS

SOURCE: MILITARY MANPOWER TRAINING REPORT FOR FY 1985

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FIGURE 2. Students and instructors assigned to individual training at military schools, FY 1985

computer science are not meant to be linked strongly to particular jobs. Characteristics of training and education that impact strongly on their cost-effectiveness in each environment are pointed out in Figure 3. Most of these relate to the fact that military services train their own personnel and assign them afterwards to the jobs for which they are trained. Courses are designed to qualify students for particular jobs, or for advanced courses that lead to particular jobs. Students receive pay and allowances while being trained, do not have to pay for their training and are assigned to jobs when courses are completed. The services realize the benefits of training when course graduates perform useful work on the job. Students benefit when completion of courses and performance on higher level jobs helps to advance their careers.

CHARACTERISTIC	TRAINING	EDUCATION
TYPE OF INSTITUTION	Military services Industry	Schools Colleges
TYPES OF COURSES	Linked to jobs	Linked to careers
COURSE LENGTH	Days to years	Semester
SCHOOL DAY	Full day	Partial day
PAY AND ALLOWANCES	Students reimbursed	Not provided
COSTS OF INSTRUCTION	Institution pays	Students pay
FINDING A JOB AFTER A COURSE	Institution assigns graduates to job	No obligation
BENEFITS		
Completing a course	Institution and student benefits	Only student benefits
Saving student time	School benefits; job benefits (earlier productivity)	No benefit to school (potential loss if school reimbursed on basis of student-days in residence) Student may increase achievement level
Increasing student achievement at school	No benefit to school (except for prestige); job benefits if school achievement transfers	No benefit to school except for prestige; student benefits if better job follows

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FIGURE 3. Some distinctions between training and education

Schools and colleges operate under different conditions. Chief among these are that courses are linked loosely, if at all, to particular jobs. Students pay for their education and do not receive any pay or allowances. Productive work on jobs after graduation yields no direct benefit to the school.

We do not believe that the ways in which people learn and retain information or that the effectiveness of various instructional strategies differs substantially between military training and education in schools and colleges. However, it seems clear that military training and schools and colleges operate under different policies and incentive systems. Some of the consequences of these differences will be discussed later.

3. IMPACT OF NEW TECHNOLOGY ON TRAINING

Some advances in technology appear particularly useful for training. Among these, one would surely include personal computers (e.g., as used for computer-assisted instruction), videodiscs, a wide array of simulators and individualized self-paced instruction as an alternative to conventional, group-paced classroom instruction. Some of the new technology is relatively inexpensive and portable, as exemplified, again, by the personal computer. This raises the possibility that certain types of training need no longer be conducted in schools but could take place in operational environments where there are few or no instructors.

It sometimes appears almost obvious that some of the new, inexpensive simulators will improve training and therefore that they should be adopted. If one wishes to be rational about this process, (particularly if non-trivial costs are involved), three key questions should be addressed:

1. Does the new technology, device, or method of instruction actually improve the effectiveness of training and, if so, by how much?

2. How much does the new technology, device, or method of instruction cost (preferably on a life-cycle basis) compared to present practice?

3. If the effectiveness of training is actually increased, is the amount of improvement worth its cost?

It would seem reasonable to adopt new training technology that offers some useful improvement in effectiveness or reduces costs or does both. In practice, the effectiveness of one method of instruction, compared to that of another, can either be more, the same or less; and the same will be true of a comparison of their costs. The various possible combinations of effectiveness and cost, and the decision which each combination favors, are shown in Figure 4.

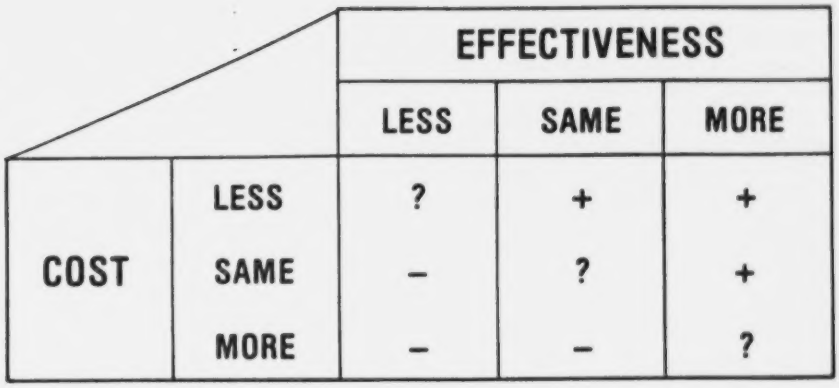

FIGURE 4. Decision diagram for evaluating the relative effectiveness and cost of two methods of instruction

New training technology can be recommended for adoption when it is more effective than current technology and costs the same or less; or when it has about the same effectiveness but costs less than current technology. New technology should not be recommended when the reverse is true, that is, when it is equally or less effective than current technology and costs more; or when it is less effective than current technology but costs about the same. It is more difficult to decide what to do when, in combination, both effectiveness and cost are more, the same, or less. Here, the issue depends largely upon whether the amount of improvement in effectiveness is worth the amount of increase in cost; and, similarly, when both effectiveness and cost are less. Where there is no significant difference both in effectiveness and cost, the appropriate decision is to do nothing. A choice can sometimes be based on some other factor not included in the evaluation; for example, if we anticipated that the supply of instructors might decrease in the future, we might accept a computer-based system that operates as well as conventional instruction does but which needs fewer instructors.

The issues raised here are aimed primarily at appraising the value of major innovations to training, such as flight simulators, computer-based instruction and

maintenance training simulators, which are considered next. However, these methods of evaluation can and, in principle, should also be applied to non-trivial innovations to training that may be procedural rather than purely technological in nature. As examples, these might include increasing (or decreasing) the length of a school day, increasing (or decreasing) the instructor-student ratio, decreasing (or increasing) the ratio of students to computer terminals and so on. Clearly, the cost of an evaluation needed to guide a decision should be small compared to the potential cost or savings associated with the planned innovation.

The following material describes comprehensive evaluations of the effectiveness and cost of three major technological innovations in military training: flight simulators, computer-based instruction and maintenance simulators.

4. FLIGHT SIMULATORS

Flight simulators are used widely now for training pilots in military services and civil aviation all over the world, but this was not always the case. Their increased use is due partly to the increased cost of fuel for flying that occurred after 1973 and partly to improved flight simulators, more realistic computer-generated imagery and high-speed digital data processing capabilities for solving flight equations. Even now, however, there are questions about how well skills learned in flight simulators transfer to actual flight in aircraft. This question arises, in part, because some modern flight simulators cost almost as much as the aircraft. There are also such questions as how much visual and motion fidelity are needed to make a simulator effective for training (this has a strong impact on its cost) and how much time should be spent, respectively, training in simulators and in aircraft. These questions cannot be avoided because simulators tend to be expensive and because pilots would rather fly in an aircraft than pretend to fly in a box on the ground.

Note that initial flight training cost about 2.3 billion dollars in fiscal year 1985 (Figure 1); this excludes the cost of advanced flight training. About 1.2 billion dollars a year is spent at present around the world for procuring new flight simulators and major modifications.

4.1 Cost

The first issue to be addressed concerns the relative costs of using aircraft or simulators for training purposes (Orlansky, Knapp and String, 1984 [2]). The variable costs of operating 39 flight simulators and corresponding military aircraft in fiscal years 1980 and 1981 are shown in Figure 5. Variable operating costs include the costs of fuel, oil, lubricants and spare parts consumed as a function of use. Using the median value, the data show that flight simulators cost 8 percent as much to use as would the comparable aircraft; a similar result was found using data for fiscal years 1976 and 1977 (Orlansky and String 1977 [3]).

4.2 Effectiveness

The next issue that must be addressed, then, is the effectiveness of training provided by using flight simulators.[3] For any particular task for which a pilot may be trained (e.g., takeoff, approach, landing), we want to know the amount of flight time saved, if any, by pilots trained in flight simulators compared to those trained only in aircraft. This is determined by means of the Transfer Effectiveness Ratio (TER) (Figure 6). The TER measures the amount of flight time saved as a function of the time spent in a simulator; it was introduced for this purpose by Stanley N. Roscoe 1971, 1972 [4,5].

Data needed to compute 34 TERs were found in 22 studies conducted over the period 1967-1977 (Figure 7); the median TER was 0.48. The median value indicates that about 0.48 hour aircraft time was saved for every 1.0 hour spent in simulators. The observed range in TERs was -0.4 to 1.9; many TERs showed appreciable savings of flight time but, in some cases, use of a simulator saved little or no time (in one case, it increased flight time).

Holman, 1979 [6] reports TERs for 24 different maneuvers on which the same 24 pilots were trained in the CH-47 helicopter flight simulator (Figure 8); the TERs range from 2.80 to 0.00. This means that this simulator provided useful training for some maneuvers (as measured by flight time saved) but not for others. An examination of the maneuvers which had low TERs suggests that the visual system of this simulator is inadequate for training in tasks that require flight control near the ground. The cost of improving the visual system (or any other major component of a flight simulator, such as a motion

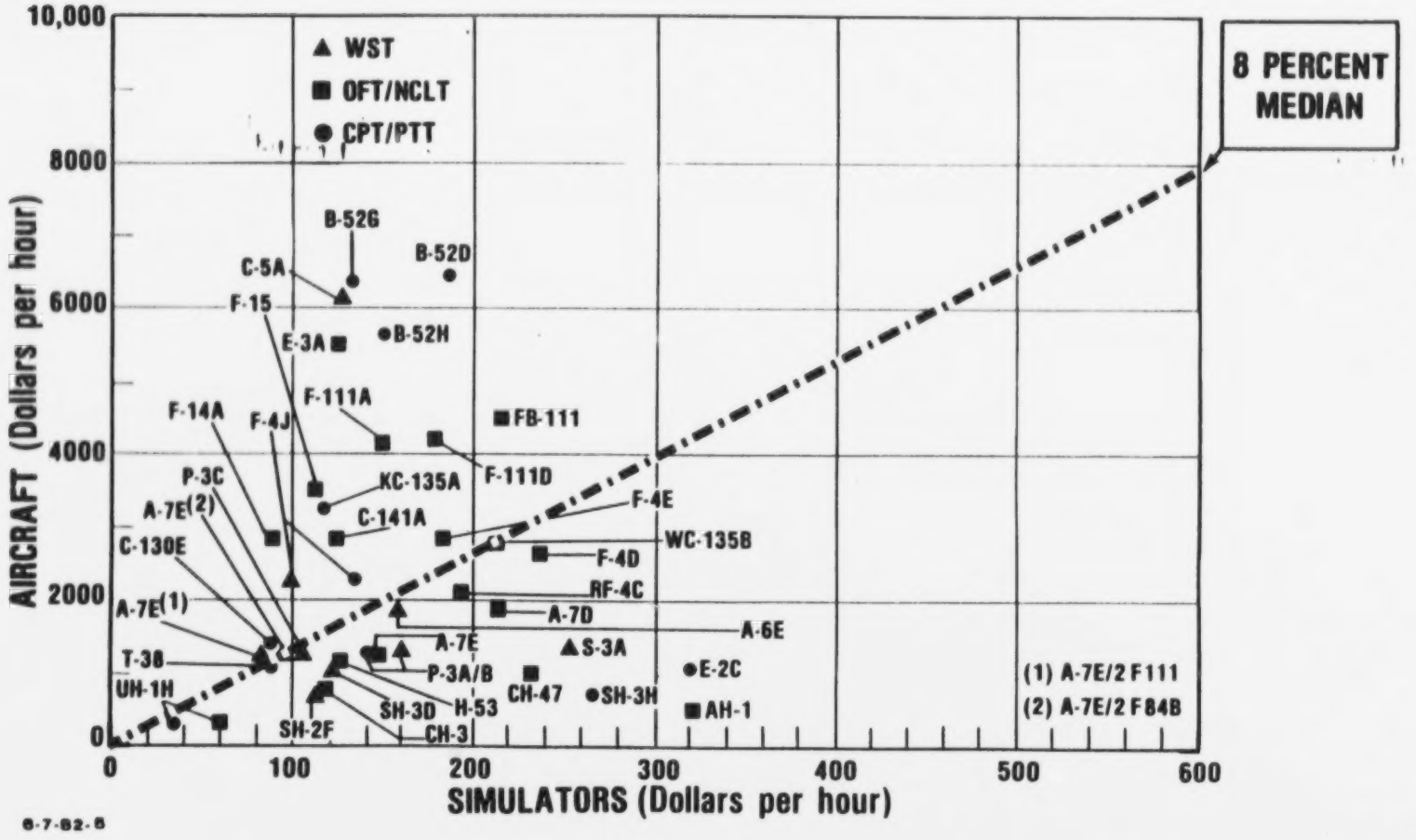

FIGURE 5. Variable operating costs per hour for 39 flight simulators and aircraft, FY 1980 and FY 1981

$$TER = \frac{A - A_S}{S}$$

A = AIRCRAFT TIME, WITHOUT SIMULATOR

A_S = AIRCRAFT TIME, AFTER SIMULATOR

S = SIMULATOR TIME

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FIGURE 6. Transfer Effectiveness Ratio (TER)

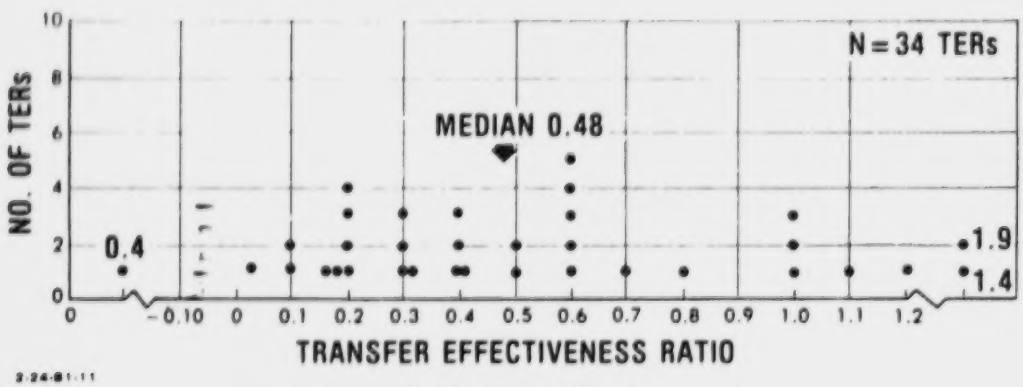

FIGURE 7. Transfer effectiveness ratios, 22 studies (1967-1977)

base) could be justified if its use resulted in higher TERs for the relevant maneuvers.

MANEUVER	TER
FOUR WHEEL TAXI	2.80
COCKPIT RUN UP	1.50
SAS OFF FLIGHT	1.33
DECELERATION	1.25
MAXIMUM TAKE OFF	1.25
GENERAL AIR WORK	1.00
STEEP APPROACH	1.00
TWO WHEEL TAXI	1.00
CONFINED AREA RECON	1.00
HOVERING FLIGHT	0.79
NORMAL TAKE OFF	0.75
CONFINED AREA APPROACH	0.75
LANDING FROM HOVER	0.69
EXTERNAL LOAD BRIEFING	0.67
TAKE OFF TO HOVER	0.63
TRAFFIC PATTERN	0.61
SHALLOW APPROACH	0.58
NORMAL APPROACH	0.53
CONFINED AREA TAKE OFF	0.50
EXTERNAL LOAD TAKE OFF	0.50
EXTERNAL LOAD APPROACH	0.50
PINNACLE RECON	0.50
PINNACLE TAKE OFF	0.33
PINNACLE APPROACH	0.00

Source: Holman, G.L., 1979.

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FIGURE 8. Transfer effectiveness ratios, 24 maneuvers, CH-47 flight simulator (trials to criterion)

4.3 Cost-Effectiveness

According to the cost data shown earlier, flight simulators cost less to operate than aircraft, i.e., about 10 percent as much. The effectiveness data show that an hour in a simulator saves about one-half hour in an aircraft. In general, therefore, flight simulators provide a costeffective method of training pilots, and continue to do so as long as the TER is about 0.10 or more. Note that both simulator/aircraft operating cost ratios and TERs can vary over relatively wide ranges. This means that specific cost and effectiveness estimates are needed to determine the training applications for which a specific flight simulator should and should not be used. This is well illustrated by the range of TERs reported by Holman for various ways of using a helicopter simulator.

The cost of buying simulators has also been compared to the amount of cost savings attributed to their use (Figure 9). The analyses are based on savings due to reduced need of aircraft flight time, less the additional costs due to the use of flight simulators. In these three cases, the net savings were sufficient to amortize the cost of procuring simulators within periods of eight months to about two years. Thus, it must be concluded that flight simulators are a cost-effective method of training pilots.

SIMULATOR	PROCUREMENT COST	SAVINGS PER YEAR	PROCUREMENT COST/ SAVINGS PER YEAR
COAST GUARD, HH-52A HH-3F	$ 3.1 M	$ 1.5 M	2.1 YEARS
NAVY, P-3C	4.2 M	2.5 M	1.7 YEARS
AIRLINE	17.5 M	25.3 M	8.3 MONTHS

FIGURE 9. Amortization of flight simulators

We have not yet considered the optimum amount of time that a flight simulator should be used for a particular type of training. None of the studies examined so far do so; they provide only point estimates for particular applications. Povenmire and Roscoe, 1973 [7] used the Link GAT-1 simulator to train pilots to pass their final flight check in the Piper Cherokee aircraft. Student pilots were given either 0, 3, 7 or 11 hours of training in the simulator before continuing their training in the aircraft. The results (Figure 10) show that larger amounts of time in the simulator led to larger amounts of time saved in the aircraft; however, the amounts of additional flight time saved diminished in the familiar shape of a learning curve.

Figure 11 shows the Cumulative Transfer Effectiveness Ratio and the Incremental Transfer Effectiveness Ratio as functions of the amount of time spent in the simulator (CTER is the same as TER). Both ratios are reduced as the amount of time in the simulator increases. This is an important finding because it permits us to

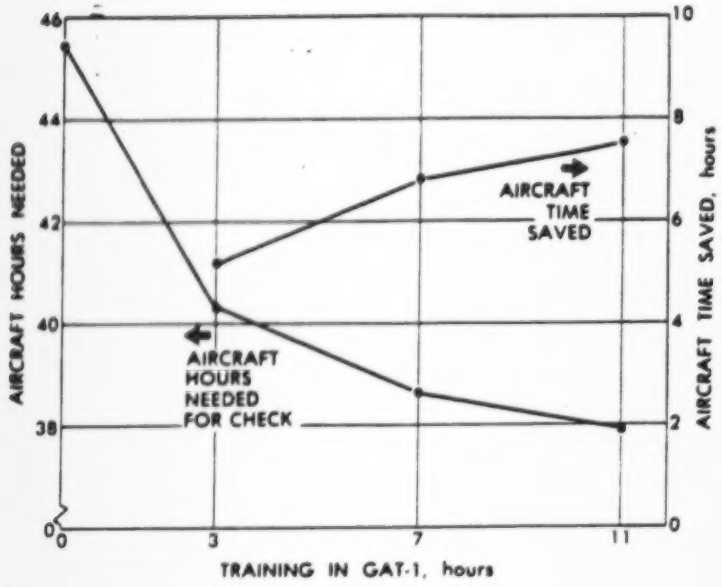

FIGURE 10. Hours needed for final flight check, Piper Cherokee
source: Povenmire and Roscoe (1973)

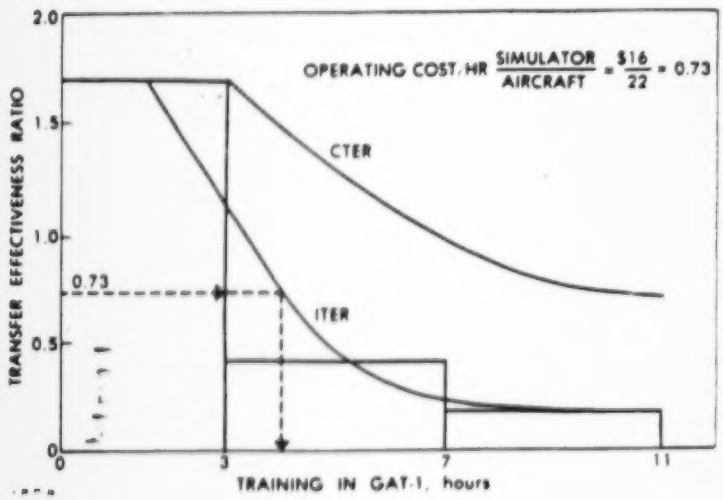

FIGURE 11. Incremental transfer effectiveness ratio (ITER) and operating cost ratio
source: Povenmire and Roscoe (1973)

determine the marginal utility of the simulator; that depends on the relative operating costs of the particular simulator and aircraft. In this case, the operating costs were $16/22 per hour or a ratio of 0.73. Training in the simulator is cost-effective until the Incremental Transfer Effectiveness Ratio drops below the simulator/aircraft operating cost ratio. This occurs at about 4 hours in the GAT-1 for training student pilots to pass the final flight check for a private pilot's license; other uses of the simulator might well produce different results.

As reported earlier, the simulator/aircraft operating cost ratio for military aircraft tends to be about 0.10, that is, much smaller than 0.73 for the GAT-1/Piper Cherokee. If the military ratio of 0.10 applied to the present data, it would have been economical to use the simulator for longer periods, perhaps as long as 10 to 20 hours.

5. COMPUTER-BASED INSTRUCTION

Instruction can be provided by methods such as independent study, lectures, discussion and tutoring and, in recent years, various forms of computer-based instruction. Various combinations of these methods are often used in a single course. The discussion that follows compares the effectiveness and cost of conventional classroom and computer-based instruction in cases where both have been used for the same course or parts of a course. Computer-based instruction is a new technology that is proposed often for use in military training. It would be particularly applicable to specialized skill training; the services offer about 10,000 skill training courses to about 1.4 million students at a cost of about 4.4 billion dollars in fiscal year 1985 (see Figure 1). These are the types of courses that qualify personnel to operate and maintain, e.g., radios, electronic and data processing equipment, weapons, medical facilities and vehicles.

5.1 Conventional Instruction

Conventional instruction is the most widely used method of instruction in military training. Instructors lecture to and discuss course material with groups of students who, as a consequence, must all proceed through the course at the same pace; conventional instruction is also called group-paced or lock-step instruction.

5.2 Computer-Based Instruction

This term is meant to include CAI and CMI. In computer-assisted instruction (CAI), lessons are stored in the computer; each student interacts with the lessons at his own pace by means of a terminal (or light pen, "mouse" or touch-sensitive screen). The computer responds by providing new material based on whether the student has answered an item correctly or incorrectly; the computer also maintains records of student progress, attendance and various administrative details. In computer-managed instruction (CMI), instruction takes place away from the computer. The student uses a lesson book and perhaps an audio-visual projector. After completing a lesson, the student takes a test that is scored by an optical reader attached to a computer. The results appear on a printer that interprets the score and tells the student what lesson to take next, e.g., proceed, try again, or report to the instructor. Except for the batch nature of the lessons and tests, the computer manages student progress and keeps records in a manner similar to CAI.

It is significant that both CAI and CMI permit each student to proceed at his own rate of learning (self-paced), to correct errors or misunderstandings as soon as they occur, and to reward him with knowledge of success when that occurs. This is difficult or impossible to achieve in conventional instruction where such knowledge is not immediately available to the instructor and where all students, regardless of their ability or style of learning, must proceed at the same pace. It is easy to overlook the fact that the pace set in conventional instruction is that needed to permit the slowest students to complete the course; in practice, the pace is set to meet the administratively acceptable failure rate and not the pace of the average learner.

Although our attention is directed to computer-based instruction, it is useful to note that the feature of self-pacing (or "individualized instruction") does not really require a computer. It is entirely possible to use the individualized lesson books characteristic of computer-managed instruction and to score the test results by hand rather than by computer. We found a few cases where individualized, self-paced instruction, without computer-support, was used for an interim period while a computer-based system was being developed and results from these instances will be reported separately.

5.3 Nature of the Data

Since 1968, at least 30 studies have compared the use of conventional and computer-based instruction for some type of military training; these studies provide 48 sets of data on student achievement and time needed to complete various courses (Orlansky and String, 1979 [8]). All studies met the criterion that the same course material was presented at about the same time to two groups of similar students whose performance was evaluated in the same way; the only difference was that one group was instructed conventionally while the other group used CBI. About half the courses studied lasted one week or less (conventional instruction) but a few lasted 2 to 10 months. About half the studies involved 50 or fewer students (CBI), but some involved 600 to 2000 students. The courses covered a wide variety of subject matters, e.g., basic electronics, electricity, medical assistant, vehicle repair, fire control, precision measuring equipment. Data were collected on 6 CAI systems and 2 large CMI systems; the studies were performed at major training bases of all three military services. Data on student achievement and time needed to complete a course were available in all studies.

5.4 Student Achievement

The measure of effectiveness used in these studies is student achievement at school, i.e., scores on progress and final tests. It is reported here for each course on the basis of whether test scores for those using CBI were the same as, superior to or inferior to those using conventional instruction (Figure 12). There were 40 courses where CAI was compared to conventional instruction. Student achievement was the same in 24 cases, superior in 15 and inferior in 1. Where achievement with CAI was superior or inferior, the differences were statistically significant but too small in magnitude to have practical significance. Student achievement at school with CMI was about the same as with conventional instruction in all 8 cases.

5.5 Savings in Student Time

The amount of time needed to complete a course given conventionally was available as baseline information; the studies provided data on the average amount of time needed to complete the same courses when CBI was used. The results are reported as percent of time saved by CBI:

$$\text{Percent of Time Saved} = \frac{\text{conventional-CBI}}{\text{conventional}} \times 100$$

METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction)			TYPE OF TRAINING
				INFERIOR	SAME	SUPERIOR	
CAI	IBM 1500	A	SIGNAL C&S		• • • •	• •	ELECTRONICS
		N	SAN DIEGO			• • • • •	ELECTRICITY
	PLATO IV	A	ABERDEEN		• • •		MACHINIST
		N	SAN DIEGO		• •	• • • •	ELECTRONICS
		N	SAN DIEGO		• •		RECIPE CONVERSION
		N	NORTH ISLAND			•	A/C PANEL OPERATOR
		AF	SHEPPARD		• •	• •	MEDICAL ASSISTANT
		AF	CHANUTE		• • • •		VEHICLE REPAIR
	LTS-3	AF	KEESLER		• •	•	ELECTRONICS
		AF	KEESLER		•		WEATHER
	TICCIT	N	NORTH ISLAND		•		TACTICAL CO-ORD. (S-3A)
	IDIOM	N	DAM NECK	•	•		FIRE CONTROL TECHNICIAN
	PLATO IV	N	DAM NECK		• •		FIRE CONTROL TECHNICIAN
				TOTAL 1	24	15	
CMI	NAVY CMI	N	MEMPHIS		• •		AVIATION FAMILIARIZATION
		N	MEMPHIS		• •		AV. MECH. FUNDAMENTALS
	AIS	AF	LOWRY		•		INVENTORY MGMT.
		AF	LOWRY		•		MATERIEL FACILITIES
		AF	LOWRY		•		PREC. MEASURING EQPT.
		AF	LOWRY		•		WEAPONS MECHANIC
				TOTAL 0	8	0	

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FIGURE 12. Student achievement at school, CAI and CMI compared to conventional instruction

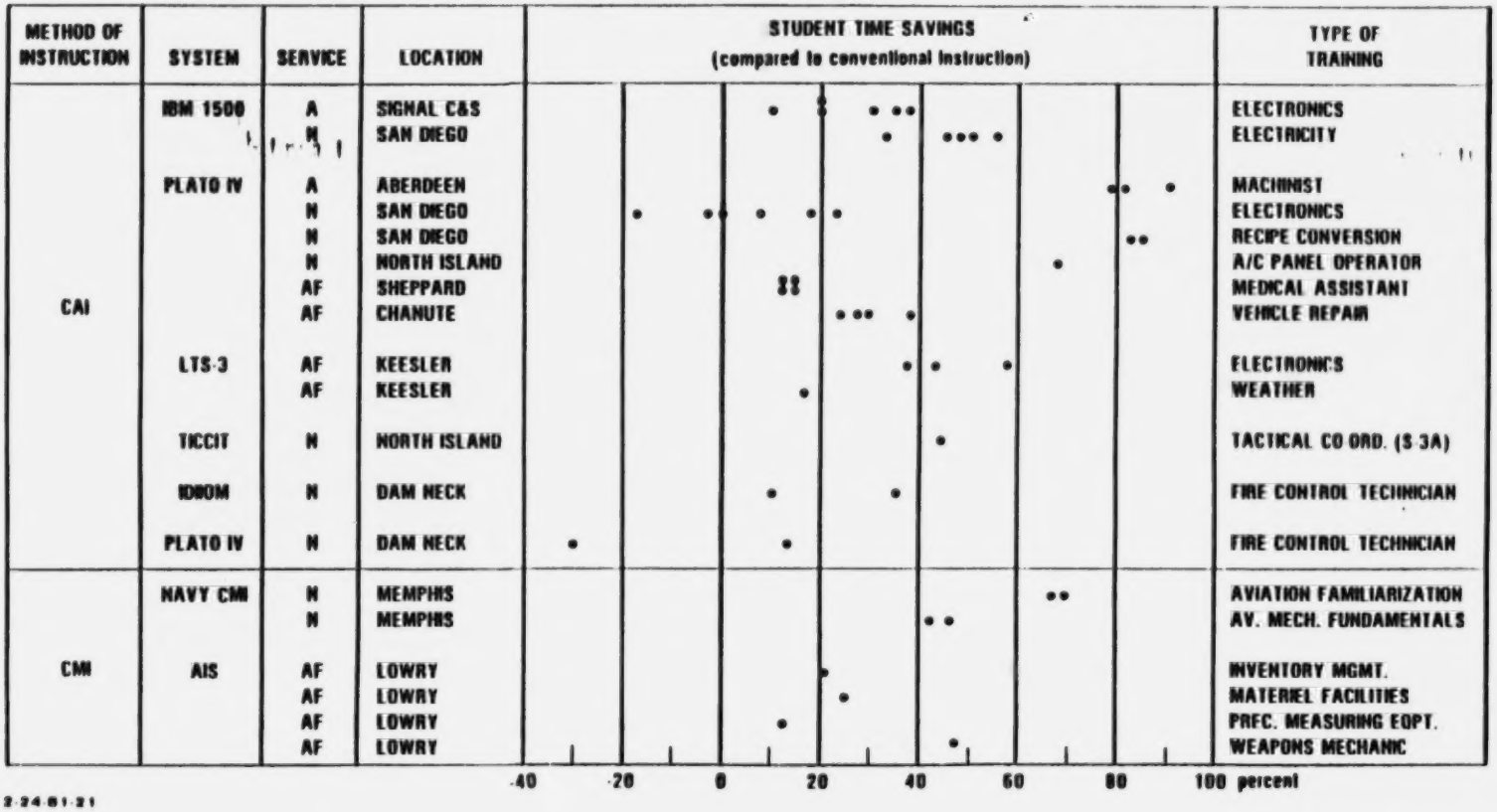

FIGURE 13. Amount of student time saved by CAI and CMI, compared to conventional instruction

The time savings range from -31 to 89 percent; the median value is 30 percent (Figure 13). The time savings may be explained simply by the fact that, with self-pacing, the faster learners are no longer held back by a pace set to accommodate slower learners.

We found 12 instances where, in a phase of development between conventional and computer-based instruction, some courses were given temporarily by self-paced, individualized instruction without computer-support. This makes it possible to compare student achievement and time needed to complete a course under three conditions: conventional, individualized and computer-based instruction.

Student achievement was about the same under all three conditions. Data on student time savings with individualized and computer-based instruction, compared to time needed when conventional instruction is used, are shown in Figure 14. It is obvious that individualized instruction saved about as much time as did either CAI or CMI (Figure 15).

NO. OF COURSES	AVERAGE AMOUNT OF STUDENT TIME SAVED		
	INDIVIDUALIZED INSTRUCTION	CAI	CMI
5	64%	69%	—
7	51%	—	51%

12-7-84-51

FIGURE 14. Average amount of student time saved by individualized instruction and CAI or CMI, compared to conventional instruction

Individualized instruction (without computer support) saves student time (50 percent or more in these cases); the addition of computer support (in the CAI and CMI

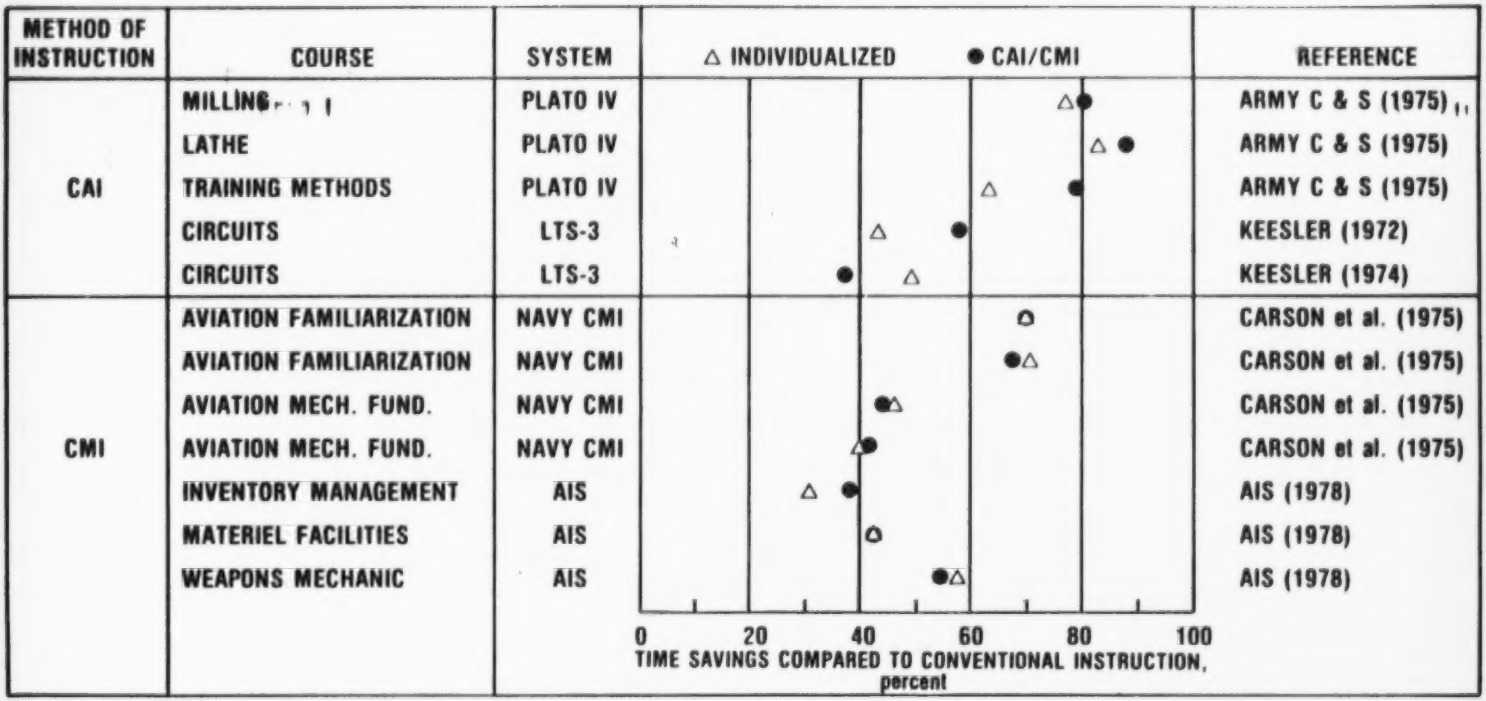

FIGURE 15. Amount of student time saved, compared to conventional instruction, by individualized instruction and by CAI or CMI on the same courses

cases) saves little or no additional time. This finding invalidates the basic argument that computer-based instruction saves training costs because it saves some of the costs of student pay and allowances; similar savings can be made without computer-based instruction just by using individualized, self-paced instruction without computers. This type of claim appears to be made because the ease of calculating savings based on reduced student time obscures its irrelevance, as noted. More careful analysis could show, of course, whether the addition of computer support does or does not save overall costs needed for instructors, support personnel, and administrative support. The issue of overall costs is not addressed by data limited to student time savings.

5.6 Cost-Effectiveness

Few of the studies that provided useful information on the effectiveness and student time savings of computer-based instruction provided cost data or performed a cost-effectiveness evaluation. It is not difficult to collect data on the costs of hardware for various computer-based systems used for instructional purposes (e.g., PLATO, TICCIT, Apple, WICAT, Commodore, Acorn, IBM and virtually all personal computers). The real problem is to estimate the costs of program development (e.g., instructional materials and programming) and program delivery (e.g., instructors, support, management, student pay and allowances) for particular applications, primarily because a data bank on these cost factors does not exist at present. Most applications often have unique requirements that are not satisfied readily by the generalized cost data that are often used in the United States and elsewhere. But that is not the whole problem. Even when more reliable and complete data on the costs of CBI systems become available, meaningful evaluation is still not possible without equivalent data on the costs of the conventional instructional systems that form the baseline for comparison.

The few published attempts to estimate the cost-effectiveness of CAI and CMI are based on incomplete analyses of the costs of instruction; no current data are reported (Figure 16). All of these studies are based on the premise that the amount of student training time saved by computer-based instruction provides major cost savings; the amounts of cost savings are estimated by computing the pay and allowances of students for the amounts of student time saved in training. The resultant amounts should more properly be called "cost avoidance savings." This

Method of Instruction	System	Service	Location	Time Savings (%)	Number of Courses	Number of Students in Experiments	Number of Students Assumed for Estimate	Estimated Savings Per Year
	PLATO IV	A	Aberdeen	65 - 89	3	535	–	PLATO IV not cost-effective[1]
CAI	PLATO IV	N	Ne Island	67	1	22	200 pilots per year	$0 57M[2]
	PLATO IV	AF	Chanute	19 - 27	4	1761	375 per week	PLATO IV not as cost-effective as programmed instruction[3]
Conventional (revised course)[4]	–	N	Memphis	50[5]	4	480	300 per class per week	$6M[6]
CMI	Navy CMI	N	Memphis	41 - 70	4	480	300 per class per week	$3M[6]
CMI	Navy CMI	N	Memphis	–	–	–	– – 52,672 graduates[8] (actual)	$ 8 9M FY 75[7] $ 9 8M FY 76[7] $10 0M FY 77[7]
CMI	AIS	AF	Lowry	24 - 35	4	–	21,128 (actual)	1417 m/yrs $ 6M (4 yrs)
	AIS	AF	Lowry	10 - 52	4	–	5561 (actual)	710 m/yrs $ 3M[10]
	AIS	AF	Lowry	0 6 - 12 5[9]	4	–	–	AIS cost-effective compared to instructor-supported self-pacing in one course, not in others; computer costs small in comparison to other school costs

[1]Due to high communication and maintenance costs. PLATO IV cost effective on basis of costs of developing and revising course materials; all comparisons with regard to self paced instruction by sound on slide or television cassette

[2]Pro rated from cost avoidance of $5 7M over 10 years *provided* other training applications found to provide full time utilization of PLATO IV terminals; the S 3A co-pilot training required only 8 percent of this capacity Baseline was workbook and use of high fidelity simulator of the Integrated Control System panel

[3]Because of greater developmental and operating costs for PLATO IV

[4]Compared to conventional instruction before revision

[5]Savings due solely to course revision

[6]Incremental to $6M above

[7]Cost avoidance savings

[8]Average on board, 6053

[9]Comparison of manually self paced instruction vs CMI in special test

[10]Derived by pro rating estimate shown above

NOTE Sources of data identified in Reference (8)

12-3-84-11

FIGURE 16. Cost savings and/or cost-effectiveness of various methods of instruction

procedure was applied to student time savings in studies of PLATO IV, Navy CMI, and the Air Force Advanced Instructional System (AIS) and, in one case, to revised course materials in a course given by conventional instruction. Four of these studies consider some other costs, such as preparing course materials, purchase or use of computers, and the number of instructors required by each method of instruction.

The dollar amounts of such "savings" can be large when a large number of students are estimated, e.g., about $10 million a year for about 50,000 students instructed in FY 1977 by the Navy CMI system and about $3 million a year for about 5,500 students instructed in FY 1978 by the Air Force AIS system. The PLATO IV system was judged to be not as cost-effective as individualized instruction, in two cost-effectiveness evaluations. These conclusions are based on incomplete cost data in two small-scale tests (Aberdeen Proving Ground and Chanute AFB). The Air Force AIS was found to be cost-effective, compared to instructor-supported, self-paced instruction in one course (Inventory Management) but not in three others; the computer costs which made the latter courses not cost-effective were judged to be small in comparison to other school costs. Since all of these results are based on incomplete cost data, the findings should not be generalized or taken as conclusive.

5.7 Discussion

A robust case can be made that computer-based, self-paced instruction is as effective, in terms of student achievement at military schools as conventional, group-paced instruction. These studies do not consider how long students retain what they have learned by either method of instruction, that is to say, whether both are equally effective in terms of performance on the job after leaving school.

Computer-based instruction also saves about 30 percent (median value) of the student time needed with conventional instruction for many different types of technical training. A few evaluations imply that computer-based instruction is less expensive than conventional instruction. However, the cost data used in these analyses are far from complete and no definitive statement can be made now about the cost-effectiveness of computer-based instruction in military training. Some factors that could significantly affect costs seem to have been neglected; these include the costs needed to incorporate new material in courses or to delete

material no longer needed (e.g., instructors and subject matter experts); to improve courses because of difficulties students find with certain lessons; costs of student attrition, if this is related to the method of instruction, and costs that arise as a function of fluctuations in student loads. In effect, cost analyses of computer-based instruction have focused primarily on the costs of procuring new CBI systems and student time savings and have not considered the life-cycle costs associated with their long-term use.

6. MAINTENANCE TRAINING SIMULATORS

Military readiness depends heavily on the effective maintenance of equipment. A peculiar feature is that some of the most advanced equipment in existence as well as some of the most outmoded must both be maintained. According to several estimates, over 25 percent of the annual budgets of the Army and the Air Force is for the maintenance of equipment [9,10,11]. About as much money is spent each year to maintain existing electronic equipment as is spent to procure new electronic equipment. [12] Non-faulty components were removed in 4 to 43 percent of all corrective maintenance actions and accounted for 9 to 32 percent of all maintenance man-hours. [13] Technicians failed to find a faulty part or damaged a good part in about 10 percent of all corrective maintenance actions.

Improved training of maintenance technicians can deal with some of these problems but not, of course, with those due to inadequate design, poor test equipment or the supply of proper tools and spare parts. The specific aspects of training evaluated here are the relative effectiveness and cost of simulators and of actual equipment for training military technicians. It might seem reasonable to use the same equipment for training at school that technicians will have to maintain later on the job. But it may be dangerous to expose novices to such equipment; it may not be easy to demonstrate many different types of malfunctions when this requires installing "failed" parts in place of good ones (this also uses up the time of instructors). Actual equipment that is designed to work under field conditions may also be expensive to procure and very expensive to maintain in operational condition for use by students.

The use of simulated equipment for training purposes has many advantages not shared by actual equipment: the computer in simulated equipment can store a large variety of common and unusual malfunctions that can be called up

easily by a control setting at the instructor's console; it can record student performance; it is reliable, rugged and safe for use by students; it may be less expensive than actual equipment. Maintenance simulators have been built in a variety of forms; some are almost indistinguishable from actual equipment; some consist of key components, mounted in "exploded" fashion on a panel board, that react to various control settings; some consist primarily of a large number of pictures and drawings of major components of a system in normal and abnormal conditions with which a student can interact, by means of a light pen or touch sensitive screen, in order to diagnose malfunctions (the displays can be stored on a video disc or microfiche system and be controlled by a computer).

6.1 Effectiveness

The purpose of maintenance training, whether with simulators or actual equipment trainers, is to qualify technicians to maintain equipment in the field. In fact, however, the effectiveness of maintenance simulators for training technicians has been compared to that of actual equipment trainers only on the basis of student performance at school and not on the job; there is one exception to this general statement (Cicchinelli, Harmon, Keller and Kottenstette, 1980).[14] The lack of job performance data to validate training applies generally to all types of military training rather than to maintenance training alone.

We found 12 studies, conducted over the period of 1967 to 1980, that compare the effectiveness of maintenance simulators and actual equipment trainers for training schools (Orlansky and String 1981) [15]; these are summarized in Figure 17. Most of the maintenance simulators in these studies are for electronics and aviation, e.g., maintaining radar, propellers, engines, flight controls, FM tuners, test equipment; one, the Hagan Automatic Boiler Control, involves an electro-mechanical system for ships. The training segments or courses in which they were used varied in length from 3 hours to 5 weeks (median 4.7 days, N = 12 courses).

Effectiveness was evaluated by comparing the scores, in end-of-course tests, of students who used simulators with those who used actual equipment trainers. There are 13 comparisons; in 12 of these, students trained with simulators achieved the same or better test scores than those trained with actual equipment; in one case, scores were

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	NO. OF SUBJECTS	COMPARISONS: SIMULATOR TO ACTUAL EQUIPMENT					
				EFFECTIVENESS				ATTITUDE TO SIMULATORS	
				POORER	SAME	BETTER	TIME SAVINGS	STUDENTS	INSTR.
Generalized Sonar Maintenance Trainer	Sonar maintenance (special course)	4 days	9		•		22%	+	
	Intermediate General Electronics	4 weeks	20		•				
EC 8	APQ-126 Radar		17					+	
	Mohawk Propeller System	3 hrs	33			•			
	Hydraulic and Flight Control	32 hrs	13		•	•		+	–
	Engine, Power Plants and Fuel	24 hrs	13	•	•			+	–
	Environmental/Utility System	32 hrs	9		••			+	–
	APQ-126 Radar	60 hrs	15		••			0/+	0/+
								+	+
	Pilot Familiarization, T-2C	18 hrs	6						+
	Flight Officer Familiarization, TA-4C	11 hrs	30						+
Generalized Maintenance Training System	SRC-20 UHF Voice Command System		20				ABOUT 50%	+	
	SPA-61 Radar Repeater	16 hrs	10					+	
Fault Identification Simulator	Hagan Automatic Boiler	5 wks	16		•		ABOUT 50%		
6883 Converter/ Flight Control Systems Test Station	F-111 Avionics Maintenance	6 days	56		•			+	0/+

FIGURE 17. Studies on the effectiveness of maintenance simulators, 1967-1980

lower. The differences, though statistically significant, were small.

A recently completed study, not included in Figure 15, shows that the accuracy of troubleshooting performance was about the same when students were trained on either the Two Dimensional Electronics Equipment Maintenance Trainer (2D EEMT) or the actual equipment (AN/SPS-10 Radar). (Cicchinelli, Keller and Harmon, 1984 [16]).

Cicchinelli, Harmon, Keller and Kottenstette, 1980 [14] compared supervisors' ratings on the job performance of technicians trained either with a maintenance simulator (the 6883 Test Station 3-D Simulator) or an actual equipment trainer. Field surveys provided data on the job performance of course graduates, some of whom were on the job as long as 32 weeks; some graduates were rated twice. The supervisors did not know how the students had been trained. Their ratings showed no noticeable difference between the performance of technicians trained with the simulator or the actual equipment trainer. The abilities of the technicians in both groups increased with amount of time on the job.

6.2 Time Savings

The automated and individualized method of instruction that is an inherent characteristic of maintenance simulators should be expected to save some of the time students need to complete the same course when given by conventional instruction (Orlansky and String 1979 [8]). Such time savings are reported in three studies [15]; compared to the use of actual equipment trainers, maintenance simulators saved 22, 50 and 50 percent, respectively, of the time students needed to complete these courses. These findings are consistent with those reported above for computer-based instruction.

6.3 Attitudes

Based on questionnaires administered at the completion of the courses, students favor the use of simulators in 9 of 10 cases and are neutral in one. Instructors are equally divided in being favorable, neutral or unfavorable to the use of simulators (about one-third in each category of response).

6.4 Costs

The cost of an actual equipment trainer is the production cost of one unit of equipment under procurement

for some military system; this does not include the costs of research, development, test and evaluation (RDT&E). Adapting a component of an operational system for use in training, such as by adding power, special inputs and controls, may require some additional costs.

We were able to get relatively complete cost data, useful for comparative purposes, on both maintenance simulators and actual equipment trainers, for 11 cases. Some of the simulators are prototypes, rather than production units; data on these simulators include the costs of research and development. The costs of research and development should be removed in order to make a fair comparison of maintenance simulators with actual equipment trainers, which are production items and exclude such costs. The number of maintenance simulators procured could also influence the cost of a single unit; this varied from 1 to 36.

We decided to use estimates which would bracket the cost of one maintenance simulator within high and low limits, as follows:

High cost estimate: Total production costs adjusted to reflect a production quantity of one; this includes the costs of research and development but not of test and evaluation. We call this the "Simulator Normalized Program Cost."

Low cost estimate: The cost of producing a follow-on maintenance simulator after the costs of RDT&E, prototypes and manufacturing facilities have been accounted for. We call this the "Simulator Unit Recurring Fabrication Cost."

The high cost estimates are shown in Figure 18. The ratio of simulator/actual equipment trainer costs is 0.60 or less for seven cases (range 0.25 to 0.55). There are four cases where this ratio varies from 1.60 to 4.00 (VTAS, MA-3, AT Trainer and AWACS). These data may be suspect for one or more of the following reasons: the costs of the operational equipments (some of which are relatively old) may have been considerably underestimated; the costs of the simulators, some of which are designed for use in research, may be high because they include capabilities not needed for routine training. For these reasons, we decided to accept 0.60 as an upper limit for the relative cost of a maintenance simulator compared to an actual equipment trainer.

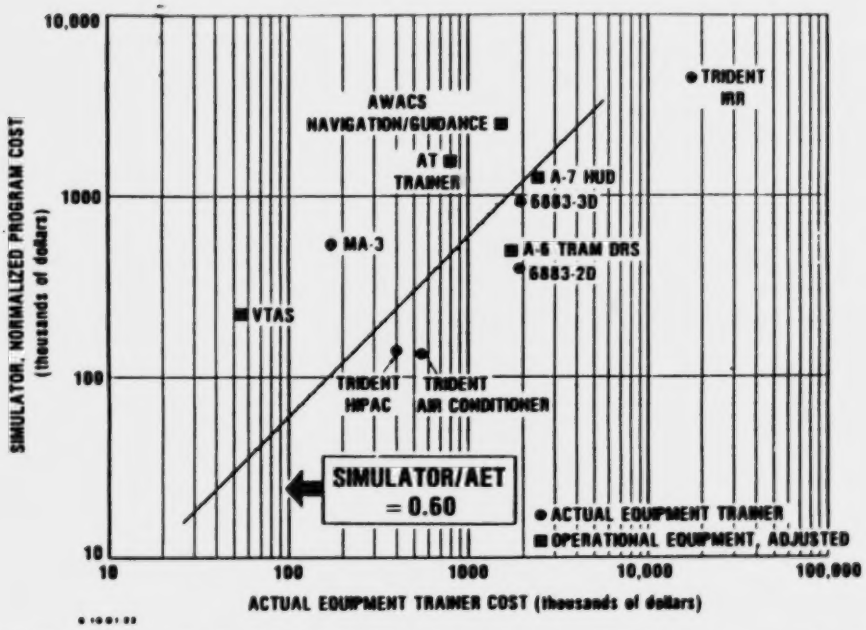

FIGURE 18. Relation between costs of actual equipment trainer and of simulator normalized program

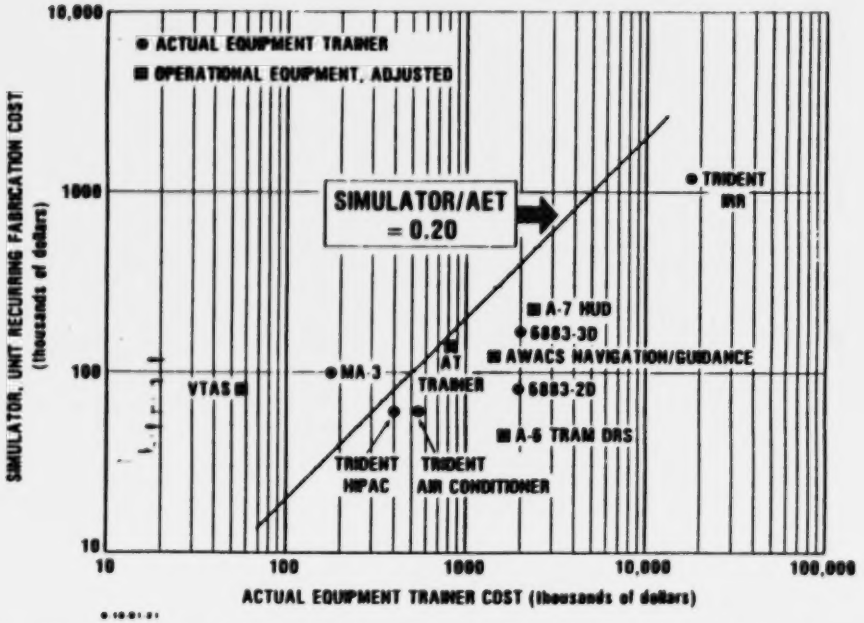

FIGURE 19. Relation between costs of actual equipment trainer and of simulator unit recurring fabrication

The low cost estimates, based on the recurring cost of these simulators, are shown in Figure 19. Nine of the 11 cases fall at 0.20 or lower; the range is 0.03 to 0.19. The two outlyers (VTAS and MA-3) are regarded as atypical for the reasons set forth above.

We conclude, therefore, that the acquisition costs of simulators generally fall in the range of 20 to 60 percent that of actual equipment trainers. These are very conservative estimates.

6.5 Cost-Effectiveness

The cost-effectiveness of a maintenance simulator on a life-cycle basis has been evaluated for the Air Force 6883 Test Stand 3-Dimensional Simulator and 6883 Actual Equipment Trainer (Cicchinelli, Harmon, Keller and Kottenstette, 1980 [14]). The three-dimensional simulator and actual equipment trainer were equally effective when measured by student achievement at school; supervisors' ratings showed no difference between the job performance of students trained either way for periods up to 32 weeks of experience after leaving school.

The life-cycle cost comparison of simulator and actual equipment trainer is shown in Figure 20. Costs were estimated in constant 1978 dollars over a 15-year period and discounted at 10 percent. The results show that the total cost per student hour was $23 for the simulator and $60 for the actual equipment trainer, i.e., 38 percent as much for the simulator for all costs over a 15-year period. The simulator cost less to procure ($595 thousand vs $2105 thousand, or 28 percent as much) and less to operate ($1588 thousand vs $3367 thousand or 47 percent as much) over a 15-year period. Savings per year were enough to amortize the acquisition costs in 3.7 years (Figure 21).

Based on initial investment costs only, the purchase of 20 2D EEMT units would cost 50 percent as much as 20 AN/SPS-10 units [16]. On a life cycle basis, the 2D EEMT costs as much as the AN/SPS-10 when 3 units of each are used; the 2D EEMT saves life cycle costs as additional units of both are procured.

Therefore, maintenance simulators are more cost-effective than actual equipment trainers for military training.

ITEM	THOUSANDS OF DOLLARS		SIMULATOR/ AET (%)
	ACTUAL EQUIPMENT	SIMULATOR	
ACQUISITION	2105	595	28
RECURRING COSTS	3367	1588	47
TOTAL	5472	2183	40
NET PRESENT VALUE (1978 dollars)	3896	1501	39
COST PER STUDENT HOUR	60	23	38

11-30-84-13

FIGURE 20. 15-year life-cycle costs of 6883 test stand 3-dimensional simulator and actual equipment trainer

AMORTIZATION	
ACQUISITION COST	$595 K
SAVINGS PER YEAR	$160 K
$\text{AMORTIZATION} = \frac{\$595}{\$160} = 3.7 \text{ YEARS}$	

6-22-81-15

FIGURE 21. 6883 test stand 3-dimensional simulator

7. DISCUSSION

We will summarize the major findings of the three training programs that were evaluated and then discuss some of the general issues that may arise when analyzing cost, effectiveness and the cost-effectiveness of military training programs or equipment.

7.1 Summary of Cost-Effectiveness Evaluations

The findings on flight simulators, computer-based instruction and maintenance simulators are summarized in Figure 22. Using student achievement at school as the main measure of effectiveness, the data show strongly that these methods of training are about as effective as the more conventional methods to which they were compared, i.e., flight simulators and aircraft, computer-based and conventional instruction and maintenance simulators and actual equipment trainers. That these different ways of training are equally effective is a robust finding; it is based on almost 100 studies of different types of training evaluated in a wide variety of applications. It leaves open an intriguing question as to why these innovations did not, at least occasionally, produce significantly increased or decreased levels of effectiveness and we will consider this below.

Even though cost analyses tend to be limited in scope, the results show a general pattern. Flight simulators cost much less to operate than do aircraft (under 10 percent as much); they save student time (the amount of flight time saved is about half that spent in simulators). On a life cycle basis, the use of flight simulators costs about two-thirds as much as aircraft for training purposes. Simulators save enough flight time to amortize their costs within about two years.

About the same is found in cost analyses of maintenance simulators and actual equipment for use in training maintenance technicians. Operating costs of maintenance simulators are closer to those of actual equipment (about 50 percent) than was found for flight simulators (where it is about 10 percent). Maintenance simulators can be amortized in about 4 years (compared to 2 years for flight simulators). There have been only a few cost studies of maintenance simulators.

Given equal effectiveness at school, a major benefit of computer-based instruction for military training is that it saves student time compared to that needed when conventional instruction is used; the median time savings

EFFECTIVENESS	FACTOR	SAVINGS OR COST		
		FLIGHT SIMULATORS	COMPUTER-BASED INSTRUCTION	MAINTENANCE SIMULATORS
ABOUT THE SAME	STUDENT TIME SAVINGS	50% OF SIMULATOR TIME	30%	20-50%
	ACQUISITION COST	30-65%	?	20-60%
	OPERATING COST	8%	?	50%
	LIFE-CYCLE COST	65%	?	40%
	AMORTIZATION	2 YEARS	?	4 YEARS

6-28-83-42

FIGURE 22. Summary of findings on the effectiveness and cost of flight simulators, computer-based instruction and maintenance simulators

is about 30 percent. This is also a strong and consistent finding. There are insufficient cost data to support a credible comparison of the costs of computer-based and conventional instruction.

7.2 Issues That Affect Costs

Determination of the resources needed to develop and use an effective training device or training program is an intriguing conceptual matter, no less so than the design of an advanced simulator. The cost analyst must determine not only which costs are relevant (or not relevant) to the purpose of his inquiry but also collect (or estimate) and analyze the relevant data, and appropriately qualify the results of his analysis. It is misleading, for example, to consider the relatively low costs of procuring personal computers or videodisc players for computer-based instruction without considering the much larger costs both of developing course materials for use with these devices and of arranging that information for computer-based control so that students can use it for instructional purposes.

As an aid in identifying the costs that may be relevant to a particular training program or device, it is helpful to have a comprehensive set of all potential costs that may apply to military training. At least one such cost element structure has been developed; it lists, defines and organizes all potential military training costs [17]; (this is described in the paper presented by Knapp and Orlansky at this Symposium).

The cost element structure was developed to permit meaningful and credible cost analyses for use in cost-effectiveness evaluations of alternative methods of training. A consistent method of costing would also permit development of a data base on costs of training and of cost models for use in analyses. No effort will be made to summarize the cost element structure here except to note that costs are organized to permit life-cycle comparisons that identify the costs of Research and Development, Initial Investment and Operating and Support; the structure is applicable to military training programs, courses and devices. The method of costing training is consistent with that used in costing other major components of a weapon system development program.

7.3 Issues Related to Effectiveness

7.3.1 School vs Job

A key issue about military training is how well it prepares personnel to perform on the job rather than just at school. Adequate student performance at school may be necessary for adequate performance on the job but it is not a measure of performance on the job--for any method of training. With some exceptions, the effectiveness of military training has almost always been measured by student achievement at school. A primary exception occurs for estimating the effectiveness of flight simulators; here, data on transfer of training from simulators to aircraft necessarily reflect job performance (there is good evidence that training in simulators transfers to aircraft). In two studies, supervisors found no difference in the job performance of maintenance technicians trained with maintenance simulators or actual equipment; the supervisors did not know how the technicians had been trained [14,16]. The general unavailability of job performance data relevant to training has been recognized; it limits our ability to evaluate the true effectiveness of many methods of training.

7.3.2 Measures of Effectiveness

The most relevant measures of effectiveness would be those most closely related to the central purpose of a course. In many countries, the designers of training courses use a method called "Instructional System Design" (ISD) that attempts to make sure that courses contain the information needed to perform adequately on the relevant job. [20] Thus, it is possible to believe that student scores on tests might be taken to indicate the level of knowledge and skill established as necessary for acceptable job performance. However, this supposition must be confirmed by empirical data before it can be accepted as a valid prediction, and this has not been done. Other measures might be time needed to diagnose correctly a representative sample of malfunctions or the percent of correct diagnoses on a test; the ability to handle on a simulator unusual events that occur rarely in real life (e.g., nuclear accidents, safety of flight, landing on the moon); skill retention, i.e., ability to perform critical tasks long after the successful completion of training. External, but still interesting, criteria about the effectiveness of training might include motivational outcomes such as attitudes to the job and willingness to work on teams with others.

The amount of time needed to complete a course is an objective measure and might be considered a measure of effectiveness. Another might be the number of students able to complete a course with a particular method of instruction. These measures also impact the costs of a particular method of instruction. A particular analysis might require that certain measures be treated as indicators of effectiveness (or of cost). Where this is not specified, we suggest that all measures that can be used to yield cost estimates be used for this purpose. The main reason is that it is easier to combine or trade-off the estimates of cost of a variety of different factors (e.g., instructors, equipment, supplies) than it is to combine different measures of effectiveness.

However, measures of effectiveness of training must ultimately be related to measures of military effectiveness and worth. These are, both in principle and in fact, the same measures of effectiveness used to develop the weapon systems to which effective training must contribute both for operations and maintenance. They are, for example, such measures as CEP (circular error probability) in gunnery, hit probability (for missiles), sortie rate (percent of aircraft performing military missions), percent of ships combat ready, and so on. This represents a challenge rather than an area of accomplishment for assessing the effectiveness of military training.

7.4 Cost-Effectiveness

Only one paradigm has been used for evaluating the cost-effectiveness of military training systems: if two methods of training are equally effective, select the one that costs less. Another paradigm is: if two methods of training cost the same, select the one that is more effective. We found no instance where this paradigm was even proposed, much less used. Given the pleasant prospect of increasing effectiveness without increasing costs, it comes as a surprise that this possibility has not been explored in research on and evaluation of military training.

We know that the military services can support the use of computer-based instruction because it is as effective as conventional instruction and that it saves costs (or, more precisely, student time). An argument can also be made that computer-based instruction can be used to increase student achievement at school with no attendant increase in costs.

Evidence to support this argument comes from two studies on the effectiveness of computer-based instruction in secondary schools and colleges (Kulik, Kulik and Cohen, 1980 [18] and Kulik, Bangert and Williams, 1983 [19]). The analytical procedure of these studies was similar to that used in the studies of CBI in military training. Student scores on final examinations were compared for courses where either CBI or conventional instruction was used; data were available for 51 comparisons in secondary schools and 54 comparisons in colleges.

An index, called "effect size" was used to estimate the differences in mean scores on final exams between the two methods of instruction (Figure 23); because schools used different scoring systems, all differences between methods of instruction were expressed in a standard way (in standard deviation units). The results are shown in Figure 24. Students using CBI achieved higher mean final exam scores than those using conventional instruction in the same courses. The effect placed them at the 63rd percentile (0.32 standard deviation units) in secondary schools and at the 60th percentile (0.25 standard deviation units in colleges) of those using conventional instruction.

$$\text{EFFECT SIZE} = \frac{\text{DIFFERENCE BETWEEN MEAN SCORE, FINAL EXAM CBI- CONVENTIONAL}}{\text{STANDARD DEVIATION, CONVENTIONAL}}$$

8-28-83-46

FIGURE 23. Definition of effect size

Figure 25 is an attempt to explain why CBI showed equal effectiveness to conventional instruction in military training and increased effectiveness in secondary schools and colleges; this explanation is speculative and needs to be confirmed or rejected. Military training is intended to prepare students for particular jobs or to enter advanced courses; the criterion for the course establishes the knowledges and skills students are expected to master by the end of the course. With computer-based instruction, students are able to proceed at their own pace towards the criterion rather than at a pace set to accommodate the entire group (including slower learners). The data show clearly that CBI saves

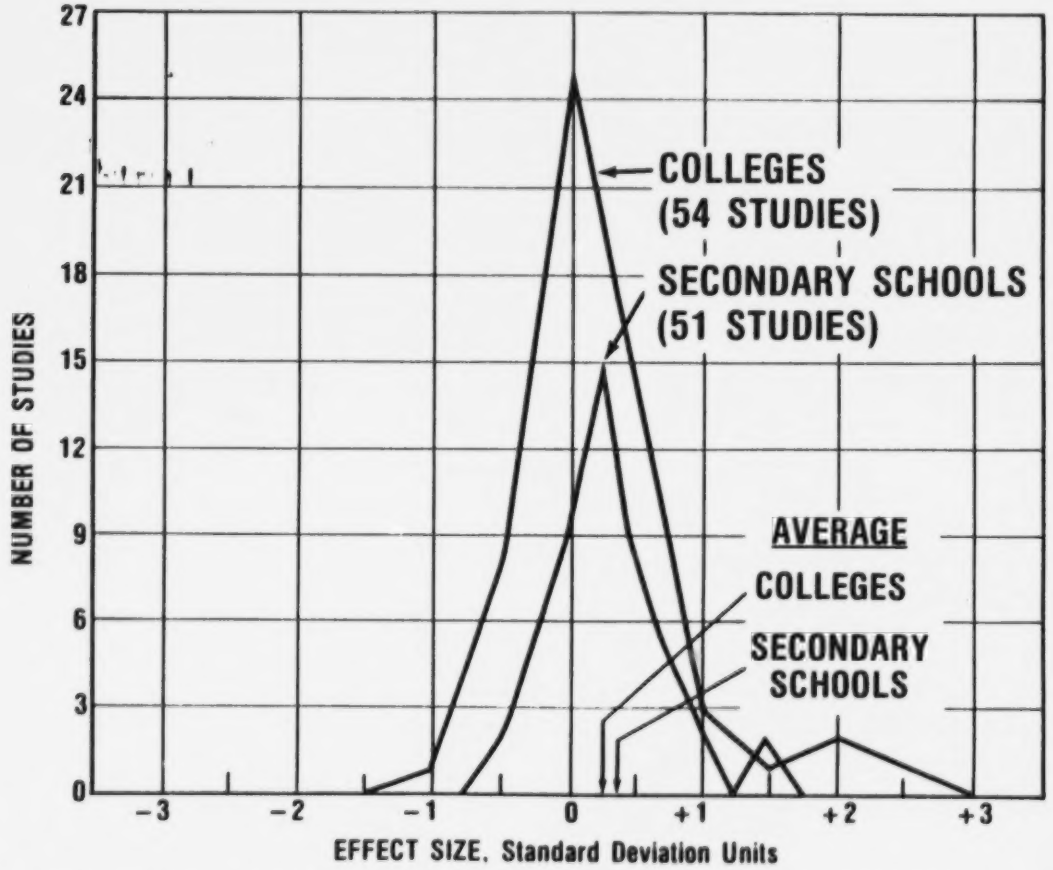

FIGURE 24. Differences on final exam scores, computer-based - conventional instruction
(source: Kulik, Kulik and Cohen, 1980
Kulik, Bangert and Williams, 1983)

average student time by allowing faster students to complete the course in less time than required by slower students in conventional instruction. All students who graduate achieve at least the minimum required criterion score.

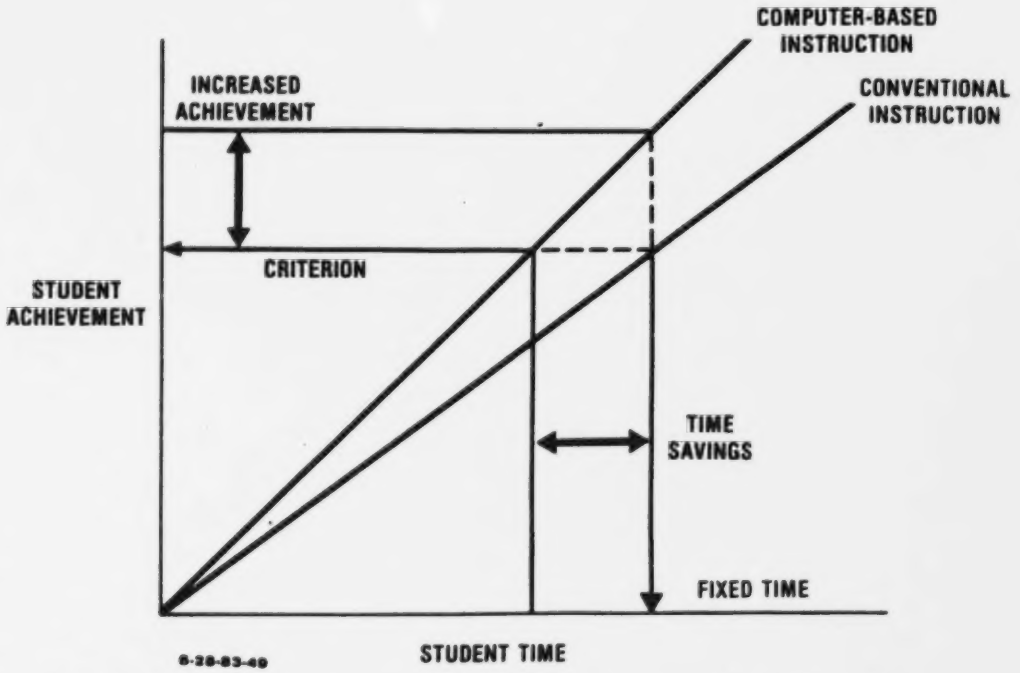

FIGURE 25. Relation between student achievement and student time

Likewise, CBI permits fast learners to proceed faster in secondary schools and colleges. Here, however, the length of time for the course is fixed and fast students are not permitted to graduate earlier. Instead, they use the additional time available to them to master more material; hence, the larger effect sizes reported by Kulik for secondary schools and colleges.

Thus, the benefit of CBI, compared to conventional instruction, can be taken either as student time savings (in military training) or as increased student achievement (in secondary schools and colleges); it should also be possible to determine the optimum combination of time savings and achievement.

For analytical purposes, it is most important to determine the relation between the cost and effectiveness of alternative methods of training (also called the trade-off,

production, or input-output function). It is almost certainly the case that increased resources can improve the effectiveness of training but only up to some limiting value; the analytical problem is to determine the point at which additional resources provide diminishing improvements. Very few studies have been designed to provide the information needed to identify the optimum combination of effectiveness and cost. Yet, some common questions about training can be answered well only if they are formulated in this way. E.g., how much fidelity is needed by a flight simulator; how long should a course really be; what is the best ratio of students-to-instructors. All of these questions need the trade-off curve between cost and performance in order to prescribe an optimum solution.

Few studies acknowledge the fact that training is a continuing process that proceeds in phases and stages from initial to advanced training, from training at school to training on the job, from individual to collective training, and from learning to forgetting. The types of questions that arise when training is viewed as a continuing process include: based on how much is retained as a function of time, what is the optimum schedule for refresher training; what is the proper mix of training in simulators and in aircraft, in primary and in advanced aircraft; what is the proper combination of school and on-the-job training to assure maximum job performance; what is the proper mix of individual and crew training; what is the proper combination of massed and distributed practice at school; between simulated and live firings; and so on. An analytical basis parallel to the one that exists for life-cycle costing has not yet been proposed for treating the effectiveness of life-cycle training (even for reasonable portions of military careers).

8. CONCLUSIONS

Substantial data show that flight simulators, computer-based instruction and maintenance simulators are as effective for training as aircraft, conventional instruction and actual equipment, respectively. Supporting cost data are less complete but still show that these innovations to training save investment, operating and life-cycle costs; the savings are sufficient to amortize investment costs in two to four years.

These findings are judged to be highly reliable. Nevertheless, certain key issues must still be addressed: the relation between effectiveness of training at school

and performance on the job; trade-offs between effectiveness and cost; and optimum sequencing of training on a life-cycle, i.e., career, basis.

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